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Contemporary considerations for the use of cardiovascular magnetic resonance imaging during pregnancy

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Abstract

Cardiovascular imaging during pregnancy is frequently used to help direct diagnosis and management for women with known or suspected cardiac disease. Although echocardiography is the most commonly used imaging modality in pregnancy, cardiovascular magnetic resonance imaging is an important and increasingly used tool, which can provide complementary, and oftentimes incremental, information regarding cardiovascular anatomy, ventricular function, and vascular flows. Advantages of cardiovascular magnetic resonance imaging over echocardiography and other imaging techniques include superior reproducibility, excellent cross-sectional evaluation of cardiac structures, high spatial resolution, and lack of ionizing radiation (a limitation of computed tomography and conventional catheter-based angiography). Cardiovascular magnetic resonance imaging in the absence of gadolinium-based contrast agents poses no known risk to the mother or fetus and its applications in pregnancy are expanding. Clinicians should be familiar with the role of cardiovascular magnetic resonance imaging in pregnancy to optimize and enhance care for mothers with heart disease.

Keywords

Magnetic resonance imaging, MRI, high risk pregnancy

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Clinical vignette

A 28-year-old woman with a diagnosis of Marfan syndrome (*FBN1* mutation) presents at 13 weeks' gestation, in her first pregnancy. She is known to have mild, stable dilation of the aortic root, as reported on her most recent echocardiogram outside of pregnancy. Her family history is remarkable for significant aortopathy in multiple first-degree relatives: her mother had a Bentall procedure to replace the aortic valve and ascending aorta due to significant dilation, two siblings underwent a Bentall procedure following aortic dissection (including emergency surgery during pregnancy at 28 weeks' gestation) and one sibling had a prophylactic valve-sparing aortic root replacement due to severe aortic root dilation. The patient is asymptomatic from a cardiovascular perspective. The physical examination is remarkable for peripheral stigmata of Marfan syndrome; however, the cardiovascular assessment is otherwise normal. An echocardiogram following clinic review reveals severe dilation of the aorta (measuring 59 mm) and a new linear echogenicity suggestive of a dissection flap (see Figure 1(a)). How should this patient be managed?

Background

Cardiovascular disease is responsible for the largest number of pregnancy-related maternal deaths in high-income countries.[1] In the developed world maternal cardiovascular disease, including hypertension, arrhythmias, valvular heart disease, heart failure, acquired or congenital disease, can severely impact pregnancy outcomes for both mother and child.[1] During pregnancy, the cardiovascular system undergoes substantial change, from the first trimester until several months postpartum. As maternal hemodynamic adaptations related to pregnancy may be poorly tolerated in patients with preexisting cardiac disease, reliable evaluation of a woman's cardiovascular status using cardiovascular imaging is often necessary to guide therapy for the best possible maternal and fetal outcomes.

Cardiac imaging during pregnancy: General considerations

Imaging modalities used during pregnancy for cardiovascular evaluation may include echocardiography, cardiac computed tomography (CT), angiography, and cardiovascular magnetic resonance imaging (CMR). Each of these modalities has inherent strengths and limitations for evaluation of various aspects of cardiovascular anatomy, hemodynamics, and function. Therefore, a deeper

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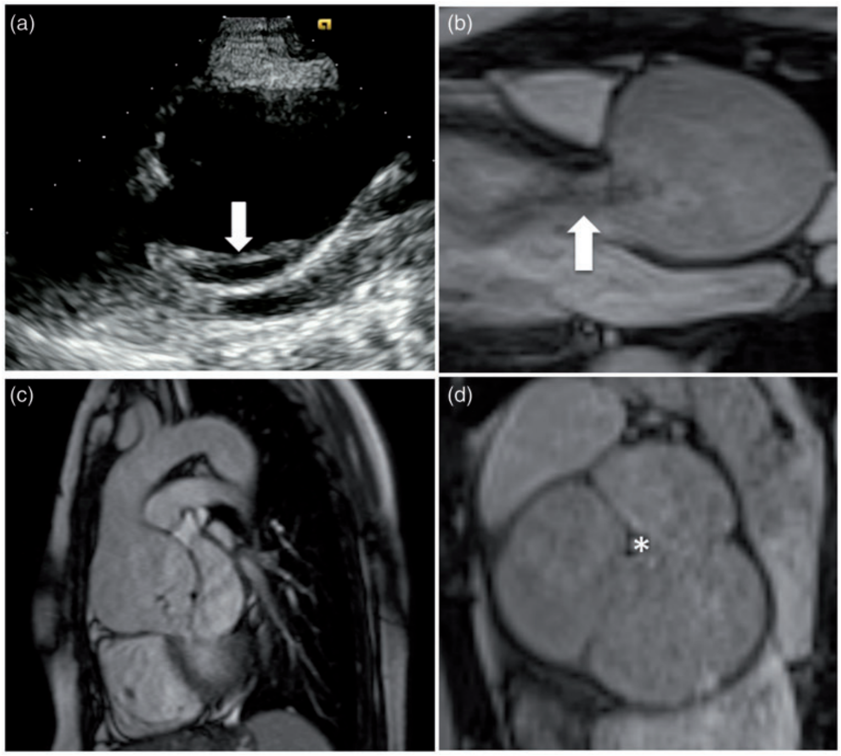

Figure 1. Twenty-eight-year-old woman with Marfan syndrome who presents at 13 weeks' gestation for evaluation. A parasternal long axis echocardiographic image demonstrating a dilated aortic root and an echogenic line (arrow) suspicious for a dissection flap at the noncoronary cusp (a). Corresponding cardiovascular magnetic resonance imaging (CMR), steady state free precession (SSFP) image shows no evidence of a dissection flap (b). Therefore, the finding on transthoracic echocardiogram was thought to be artifact. Notice the severe aortic regurgitation jet (arrow). A sagittal oblique SSFP MR image demonstrating severe dilation of the aortic root with no evidence of a dissection flap (c). A short axis SSFP MR image in the aortic valve plane shows a dilated aortic root measuring up to 59 mm and central coaptation defect (*) as the cause for the severe aortic regurgitation (d).

Table 1. Imaging modalities used in pregnant women.

	Cardiac chamber size	Ventricular function and mass	Valves	Great vessels	Coronary arteries	Safety precautions
TTE	++	++	++	+	–	None
TEE	+	+	+++	++	–	Considerations for sedation and airway management[a]
CMR	+++	+++	+	+++	+	Avoidance of gadolinium contrast
CT[b]	+++	++	+	+++	++	Radiation precautions
Angiography	–	–	–	++	+++	Radiation precautions

CMR: Cardiovascular magnetic resonance imaging; CT: computed tomography; TEE: transesophageal echo cardiography; TTE: transthoracic echo cardiography.
[a]Consultation with anesthesia may be reasonable in late pregnancy to ensure proper airway protection and appropriate sedation.
[b]Although cardiac CT has superior spatial resolution with respect to other imaging modalities, relatively inferior temporal resolution and associated radiation limits its wider application in pregnancy.

understanding of each of these modalities can facilitate the care of pregnant patients requiring cardiovascular imaging (Table 1).

Currently, the most commonly used imaging modality in pregnancy is transthoracic echocardiography due to its widespread availability, portability, and safety.[2] Echocardiography provides information on cardiac anatomy, ventricular function, chamber dimensions, wall thicknesses, and valvular morphology/function with excellent temporal resolution. However, echocardiography has some important limitations including limited field of view, moderate inter/intra-observer variability,[3,4] geometric assumptions for quantification of ventricular volumes, ejection fraction and mass, as well as lower spatial resolution (ability to visualize small structures) as compared with other imaging techniques.[5]

Transesophageal echocardiography is a more invasive imaging technique but can be safely used during pregnancy. Indications typically include a more detailed evaluation of valves, interrogation of small intracardiac structures or to rule out intra-cardiac thrombus. However, it should be recognized that an increased risk of aspiration exists during pregnancy. Additionally, fetal monitoring should occur if sedation is given. Depending on the clinical question, transthoracic or transesophageal echocardiography may not provide sufficient information, and additional cardiac imaging may be required.

Chest and cardiac CT can be used in pregnancy to rule out aortic dissection, acute pulmonary embolism, or disease involving the coronary arteries. However, CT has the disadvantage of radiation exposure to both mother and fetus; therefore, CT, in general, is not a first-line test and should be avoided unless the clinical question cannot be answered by imaging modalities that do not involve radiation (such as echocardiography, CMR etc.).[6]

In the event of a suspected acute coronary syndrome, conventional catheter-based coronary angiography should be performed expeditiously. Catheter-based angiography is essential for establishing a diagnosis and allows for angioplasty and stenting without delay, if necessary. In addition to atherosclerotic coronary artery disease, conditions such as coronary artery dissection or coronary thromboembolism may be found, and these may be precipitated by pregnancy. The main concern pertaining to angiography during pregnancy relates to fetal radiation exposure. However, evidence suggests that there is no increase of fetal congenital malformations with radiation exposure of a standard angiogram or angioplasty.[7]

Due to the limitations of echocardiography and undesired side effects of radiation with CT and conventional angiography, CMR has an expanding role in the imaging armamentarium of the clinician caring for pregnant women with known or suspected cardiac disease. Following CMR, diagnoses can be firmly established and further care can be facilitated. However, as CMR is not frequently used in pregnant patients, clinicians may not be familiar with the role of CMR during pregnancy.

CMR applications in pregnancy

Use of CMR is well established in the nonpregnant population and has increasing applications in pregnant women. CMR is not typically used as a first-line cardiac imaging test, but rather is used as an adjunct to echocardiography to help provide improved visualization and more accurate information on chamber size, function, tissue characterization, cardiac shunts, or evaluation of the entire aorta (typically incompletely evaluated by transthoracic echocardiography).[6] Establishment of normal hemodynamic remodeling in pregnancy using CMR has been described in the literature and with the baseline CMR data for structural and hemodynamic changes for normal pregnancies now published, there is an existing frame of reference for the interpretation of abnormal changes seen in maternal cardiac disease states.[8]

CMR has several advantages over echocardiography and CT, which render it an attractive option for noninvasive cardiac imaging in pregnancy. First, CMR is highly reproducible and accurate for determination of cardiac volumes and ventricular function. Second, it provides superior spatial resolution and enhanced distinction between blood and myocardium making it the gold standard for evaluation of ventricular function. Third, it allows for cross-sectional imaging of structures that are not well visualized on echocardiography. Lastly, it does not use ionizing radiation.

Indications for CMR during pregnancy include imaging of pregnant women with known or suspected cardiovascular disease where the cardiovascular structures of interest are sub-optimally imaged by echocardiography, or where tissue characterization of CMR is required. As CMR is not limited by patient imaging "windows" used in transthoracic echocardiography, CMR provides a much more accurate cross-sectional evaluation of the right ventricle, cardiac chamber dimensions, ventricular function, and the thoracic aorta (Figure 1). Published literature reports the use of CMR to delineate specific cardiovascular conditions suspected in pregnancy, including: aortic coarctation,[9] aortic dissection,[10] peri-partum cardiomyopathy,[11,12] and maternal congenital heart disease.[13] Outside of improved visualization, CMR allows for tissue characterization that is not possible using echocardiography. CMR has been used in pregnancy to evaluate and diagnose intra-cardiac masses,[14] acute myocardial infarction,[15] cardiac blood cysts,[16] in addition to evaluation of the myocardium for iron overload (Figure 2). CMR can be a

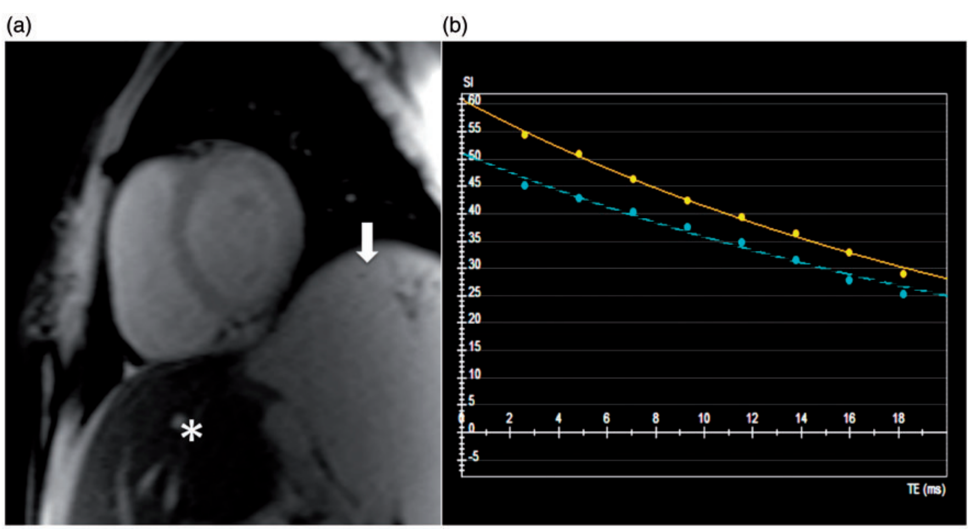

Figure 2. Twenty-nine-year-old woman with beta thalassemia who underwent CMR evaluation at 35 weeks' gestation for assessment of myocardial iron overload. A targeted CMR image multiecho gradient sequence in a short axis oblique plane (a, basal slice shown) was performed to assess for drop in signal within the interventricular septum that is typically caused by the paramagnetic effects of nonprotein bound iron. Note the dark signal of the liver (*) indicating liver iron infiltration and splenomegaly (arrow). A parameter known as T2* is calculated based on the exponential decay curve (b) where the loss of signal over time is accelerated in the presence of myocardial iron. This patient had no evidence of myocardial iron overload based on analysis of 2 regions of interest (top and bottom lines) in the inter-ventricular septum showing normal T2* values of 28 -50 ms (iron typically present if T2* <20 ms). CMR allows noninvasive assessment of myocardial iron that would impact decision to initiate chelation therapy during pregnancy to reduce complications such as heart failure or arrhythmia.

valuable tool in cardiovascular imaging and may provide additional information above and beyond that of standard echocardiography in diagnosing and managing pregnant patients with cardiovascular disease.

The major limitations to CMR include limited availability, inferior temporal resolution compared to echocardiography with limited visualization of the valves or small mobile structures, and moderate image acquisition time, potentially preventing imaging of acutely ill patients.[2] CMR is contraindicated in patients with inner ear prostheses or metal fragments in the eye and those with certain pacemakers and implantable cardiac defibrillators due to concerns with device heating and malfunction. The use of the CMR contrast agent gadolinium is generally not recommended in pregnancy due to the potential for adverse outcomes in offspring (see below).[17]

Considerations for scanning a pregnant patient with CMR

Acquisition time for a CMR can be up to 45 minutes depending on the sequences required to evaluate the desired cardiac structures. However, shortened CMR sequences may be used to answer a focused question (i.e. anatomy of the aorta). Positioning the patient in the magnet for image acquisition may be uncomfortable for some patients during longer scan times, especially in the third trimester due to the size of the gravid uterus, which can compress the inferior vena cava. Later in pregnancy the woman should be positioned in the left lateral decubitus position. This can be achieved with a wedge-shaped pillow under the right side, to support the patient and will prevent inferior vena caval compression during prolonged scan time. In rare cases, CMR may be poorly tolerated by those with claustrophobia due to the narrow space within the bore of the magnet. Imaging with the patient's head outside of the magnet, or use of larger bore magnets, if available, may relieve some anxiety without the use of sedative medication.

Safety of CMR during pregnancy

Noncontrast CMR has not been associated with any clear risk to the fetus and allows for detailed noninvasive assessment of maternal as well as fetal anatomy and physiology.[18,19] CMR should be considered when the information provided will have an important impact on how the patient is managed during pregnancy, for decision-making regarding method of delivery and/or for risk prognostication. If a CMR is necessary during pregnancy, it should be focused to answer the most pertinent clinical question(s) with tailoring of the scan sequences to image only what is absolutely necessary in order to minimize the total time in the magnet. Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to a radiofrequency electromagnetic field such as that used for CMR. Where possible, CMR sequences with the lowest SAR should be used to reduce the potential risk of heat deposition in the mother and fetus.

A recent observational study of 1,424,105 deliveries, including 5654 women who underwent magnetic resonance imaging (MRI) of various organs during pregnancy, demonstrated that exposure to MRI during pregnancy (including in the first trimester) compared with nonexposure was not associated with increased risk of harm during follow-up to early childhood. However, in general, gadolinium is best avoided during pregnancy as there are no clear safety data and exposure to gadolinium-based contrast agents has been associated with an increased risk of adverse events in offspring. A study of administrative data by Ray et al. demonstrated an association between exposure to gadolinium-based contrast agents during pregnancy and later development of rheumatologic, inflammatory, and infiltrative skin conditions in children (123 events in the exposed group with an adjusted relative risk of 1.36 (95% confidence interval 1.09–1.69)), as well as a very small risk of stillbirth and neonatal death (7 reported cases in 397 exposed pregnancies with an adjusted relative risk of 3.7 [95% confidence interval 1.55–8.85]).[17] Limitations of this study include the inability to establish causation given its observational nature and the relatively low number of major adverse events. Contemporary guidelines continue to advise against the routine use of gadolinium for CMR during pregnancy.[20] However, there may be instances where gadolinium is warranted and the risk versus benefits profile needs to be evaluated on a case-by-case basis. It should be noted that CMR sequences can be manipulated to show angiographic-like images in order to visualize vascular anatomy without the need for injection of contrast agents. Image quality may occasionally be compromised without the use of gadolinium-based contrast agents but are often sufficient to answer the clinical question of interest. Future development of parametric imaging (T1 and T2 mapping) may further improve tissue characterization without the need for intravenous contrast administration.

Newer applications of CMR in pregnancy: Maternal and fetal flows

In recent years, CMR has been used to evaluate the magnitude of the change in cardiac output that occurs during the third trimester of pregnancy compared to baseline in both normal patients and in patients with moderate to severe cardiac disease.[21] This work may provide an insight into how normal adaptive changes in the maternal cardiovascular system affect the cardiac structure in patients with preexisting moderate to complex cardiac disease and how these changes are tolerated. In addition, CMR has also been used for detailed evaluation of fetal cardiovascular anatomy and physiology. Phase-contrast flow analysis is currently the gold standard for the noninvasive measurement of blood flow. Recent work in fetal medicine has developed a fetal imaging technique for phase-contrast flow measurements using CMR.[22] This retrospectively constructed CMR technique known as "metric optimized gating" allows for accurate phase-contrast measurements of the fetus late in gestation.[23] During CMR evaluation, noninvasive assessment of fetal Oximetry can also be achieved. The differing magnetic properties between oxygenated and deoxygenated hemoglobin allow for estimation of fetal oxygen saturation using CMR. This technique has been shown to be accurate in children and is an active area of research in the fetus.[24]

Summary

Cardiovascular disease is an important cause of maternal morbidity and mortality, and frequently requires cardiovascular imaging to confirm the underlying diagnosis and to guide clinical management. Cardiovascular imaging in pregnancy should be tailored to best answer the clinical question with the lowest risk to mother and fetus. Of the many imaging modalities available, each has its strengths and limitations in evaluating different cardiac structures, and the clinician should be familiar with the information each test can provide with inherent risks weighed against potential benefits. The role of CMR in pregnancy is expanding; and as an imaging modality, CMR without the use of intravenous gadolinium contrast can provide incremental information regarding maternal cardiac anatomy, physiology, and function, above and beyond standard techniques, without additional risk to the mother or fetus.

Conclusion to vignette

Beta-blocker therapy was commenced (metoprolol 25 mg by mouth twice daily). An urgent CMR study was arranged to rule out dissection at 13 weeks' gestation in this woman with Marfan syndrome and severe aortic root dilation. The CMR examination was tailored to focus on the thoracic aorta using single shot steady-state free-precession (SSFP) imaging (axial to cover the thorax and abdomen and sagittal oblique views across the aortic arch) and cine SSFP imaging (three chamber view and cross-sectional stack across the aortic root) (see Figure 1(b) to (d)). Dissection of the aorta was excluded. Severe dilation of the aortic root was confirmed. The patient was felt to be at very high risk of dissection in pregnancy given her aortic dimensions and dissection in multiple first-degree relatives and was therefore referred for surgery. A valve-sparing aortic root replacement was completed at 14 weeks' gestation with no hypothermic or circulatory arrest (temperature maintained at 36°C, direct cold cardioplegia was directed to the coronary arteries). There were no maternal or fetal complications related to surgery. This patient went on to deliver a healthy infant at 38 weeks' gestation by elective caesarean section. The infant was subsequently found to be negative for the *FBN1* mutation that was documented in the mother.

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